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Procedia Engineering 25 (2011) 1493 – 1496

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

Evaluation of Thin Film Indium Bonding at Wafer Level

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Abstract

We propose a thin film indium thermocompression bonding for which neither flux nor reducing atmosphere is needed. By an optimized patterning of the evaporated indium film and the lid, surface hermetic bonding on wafer level is reached without exceeding 140 °C in any step of the procedure. Different designs of the indium metallization and lid were tested to improve bond strength while keeping the same bonding parameters. By depositing an adhesion layer of CrAu on the lid, the bond strength can be increased by 30 % compared to the one of indium to glass bonding. Another way to increase bond strength by 40 % is to profile one bonding surface in such a way that the indium oxide breaks at multiple places within the deposited area. Hermeticity is proven for all different designs.

Keywords: Indium; low temperature bonding; MEMS packaging; thermocompression; hermetic

1. Introduction

Hermetic packaging is required for applications where a component has to be shielded from the environment. For sensitive components the requirements are even stricter and they demand for a fluxless low temperature bonding technique in vacuum or inert atmosphere. For direct bonding techniques at low temperature an absolutely smooth and clean surface is needed [1]. In contrast, intermediate layer bonding can level out uneven surfaces and materials can be chosen according to temperature and hermeticity requirements.

Indium, with a melting temperature of 156.7 °C, is commonly used as a low-temperature, fluxless soldering material in micro-electro-mechanical system devices as molten indium has good wettability on many surfaces at low process temperatures. It has the ability to accommodate large plastic strains and can

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doi:10.1016/j.proeng.2011.12.369

therefore be used for applications where large thermal expansion mismatches occur. The native oxide layer reduces indium's ability to be bonded. A bonding can only occur if pure indium gets in contact with a non-metallic surface like glass, mica, quartz, glazed ceramics, or some metals [2-4]. Breaking of the oxide skin can be done either by mechanical means like compression of the indium layer or by etching the oxide layer. An active atmosphere can prevent the excessive growth of the oxide while heating the indium above its melting temperature [5]. Indium can also be covered by a layer of gold or silver to prevent it from oxidation.

Thermocompression bonding without oxide removal is reported for layers thicker than 50 µm. Indium is used for bump bonding but a reflow at temperatures higher than the melting temperature of indium is needed [6]. By using a reflow process at 180 °C for indium rims a hermetic seal can be reached [7]. We show in this work that a hermetic bond can be reached with thin layers of indium without flux or any oxide removal at a temperature of 140 °C. Sample preparation and bonding process are described as well as bond strength and basic hermeticity evaluated.

2. Sample preparation and bonding process

A glass wafer is patterned with 52 rims with an inner diameter of 6 mm by evaporation and lift-off. The width of the In rim is either 200 µm or 40 µm. Cr is used as an adhesion layer for In. For designs in which the adhesion layer is wider than the In, Cr would oxidize but CrO_2 is not wetted by In. Therefore an additional Au layer is deposited as oxidation barrier layer on top of Cr. During bonding In spreads, forms $AuIn_2$, and gets in contact with pure Cr. The top wafer is in all four cases a Pyrex wafer, which is patterned with 1 µm spikes for design B and with CrAu for design D. All designs are shown in Fig. 1.

Bonding is done in a SB6 E wafer bonder from Suss MicroTech at 140 °C and 0.8 MPa for 30 min at a vacuum level of $5*10^{-3}$ mbar. By working under vacuum and keeping the temperature lower than the melting point an excessive growth of In_2O_3 is avoided [8]. A yield of at least 92 % of successfully bonded rims is reached after dicing. The exact number for each design is shown in Tab. 1.

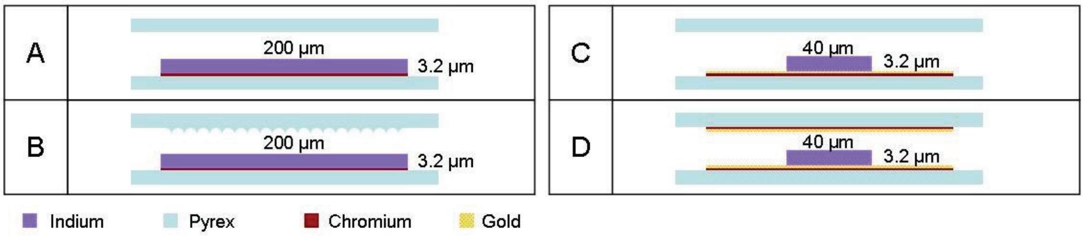


Fig. 1: Schematic drawing of four different designs. Adhesion layer and indium of design A and D are 200 µm wide. Indium width in design B and C is 40 µm. Depth of lid profile in design B is 1 µm. Indium height is 3.2 µm for all designs.

3. Evaluation of bonding and discussion

3.1. Hermeticity tests

The wafers are diced into 10x10 mm^2 samples. Basic hermeticity is tested by emerging the samples in an isopropanol bath. At least 90 % of the samples were tight before and after dicing (see Tab. 1). High hermeticity of the In bonding is confirmed on chip level by encapsulating a few micrograms of the highly reactive alkali metal rubidium. Any oxygen that will enter the cell will react with Rb to form Rb_2O.

Tab. 1: The bonding is done on wafer level and the wafer diced afterwards into 10x10 mm samples. By emerging them into an ispropanol bath basic hermeticity is tested.

Design	A	B	C	D
Yield after dicing	50/52	48/52	52/52	52/52
Isopropanol tight	50/52	47/52	52/52	50/52

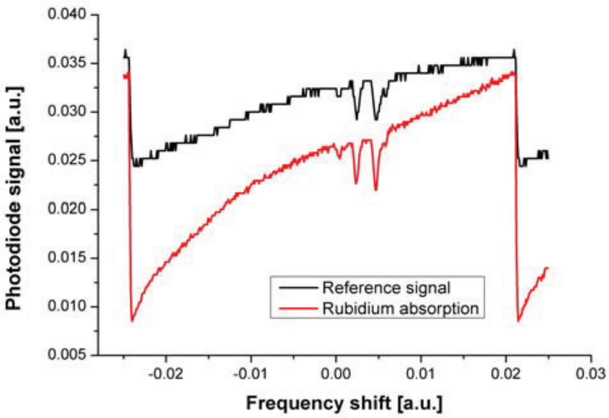


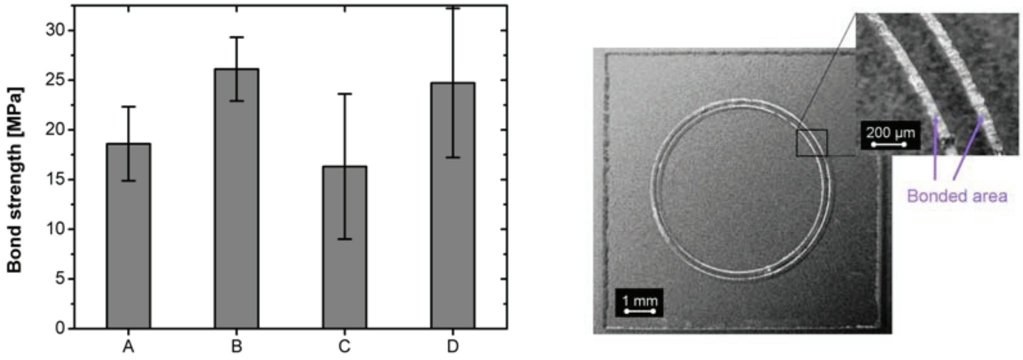
Fig. 5: Absorption spectrum of rubidium at 90°C in the indium bonded cell compared to the signal in a commercial glass blown rubidium cell at room temperature.

By scanning a laser's frequency around the absorption lines of Rb and detecting the light transmission through the Rb cell, the absorption spectrum is attained (see Fig. 5). The height of the peaks corresponds to the partial pressure of Rb vapor in the cell. The melting point of Rb is 39.3 °C and a cell with a thickness of 390 µm has to be heated to around 90 °C to obtain a reasonable absorption spectrum. The cell with Rb shows an absorption spectrum for more than four months if kept at room temperature.

3.2. Pull tests

Bond strength is measured with a pull test setup (Instron model 3344) for a minimum of 17 samples per wafer and the results are shown in Fig. 2a. Average bond strength for a 200 µm wide In rim bonded to a Pyrex wafer (Fig. 1A) is 16.3 MPa (σ=3.1 MPa). By examining the bond rims after pull test it is clear that bonding mainly occurs where pure In is squeezed out of the oxide skin and touches glass (Fig. 2b). However, for calculation of the bond strength the total area of the originally deposited In plus the area of the spread In is taken into account.

One way to increase the bond strength is to profile the lid to break the oxide within the deposited area (Fig. 1B). The area where pure In gets in contact with glass is increased and results in an average bond strength of 26 MPa (σ=3.2 MPa). If the aspect ratio of the deposited In is increased by reducing the width to 40 µm (Fig. 1C) the average bond strength decreases by 12 %. If the Pyrex lid is patterned with a CrAu adhesion layer (Fig. 1D), bond strength can be improved again to an average of 24.7 MPa (σ=7.5 MPa). However, a decrease of the volume of the In for one bond rim leads to a thinner final bond which is more susceptible to the non-planarity of the bonding tool and an increase in the standard deviation can be observed.



(a) (b)

Fig. 2: (a) The graph shows the average bond strength with the standard deviation of 17 samples for each design. (b) Microscope picture of bonded lid after pull test (design A). Bonding occurred mainly outside the originally deposited film.

4. Conclusion

Thin film indium wafer bonding at 140 °C, without flux or oxide removal before bonding, leads to bonds with average bond strength up to 26 MPa. It is expected that by increasing the aspect ratio but keeping the same volume of the deposited indium or by combining CrAu adhesion layer with profiled lids, the temperature for the bonding can be lowered while keeping the same bonding pressure.

Indium bonding has been proven to be hermetic for more than four months at room temperature. Quantitative leak rate measurements will be used to prove reliability of thin film indium bonding.

Acknowledgements

The authors thank the CMi EPFL and CSEM Microsystems Division C cleanroom staff and the project partners, especially LPM EPFL and LTF UniNE, for their help and useful discussions. This work was supported by the Swiss National Science Foundation (Sinergia grant CRSI20-122693/1).

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